



Wadis as dryland river parks: challenges and opportunities in designing with hydro-ecological dynamics

Sareh Moosavi, Margaret J. Grose & Philip S. Lake

To cite this article: Sareh Moosavi, Margaret J. Grose & Philip S. Lake (2019): Wadis as dryland river parks: challenges and opportunities in designing with hydro-ecological dynamics, Landscape Research, DOI: [10.1080/01426397.2019.1592132](https://doi.org/10.1080/01426397.2019.1592132)

To link to this article: <https://doi.org/10.1080/01426397.2019.1592132>



Published online: 31 Mar 2019.



Submit your article to this journal [↗](#)




Article views: 9



View Crossmark data [↗](#)



Wadis as dryland river parks: challenges and opportunities in designing with hydro-ecological dynamics

Sareh Moosavi ^a, Margaret J. Grose^a and Philip S. Lake^b

^aFaculty of Architecture, Building and Planning, The University of Melbourne, Melbourne, Australia; ^bFaculty of Science, Monash University, Melbourne, Australia

ABSTRACT

Dryland rivers (*wadis* in Arabic) are characterised by high levels of flow unpredictability due to their severe dry-wet hydrological regimes. In the Arabian Peninsula, recent attention has focused on revitalising the socio-ecological values of wadis by rejuvenating them as linear public parks. In this paper, we review the key hydro-ecological characteristics of wadis and examine a range of design responses to address their dynamics in urban areas. Three case studies of recent and ongoing rehabilitation projects in Muscat, Oman, were spatially analysed and interviews with stakeholders involved in the projects were conducted. Design strategies and system-based approaches were suggested, including taking account of the hydro-ecological processes and relationships across multiple spatial and temporal scales, interdisciplinary collaborations, and testing the systems' performance through design experimentation. The findings can be applied to the rehabilitation of ephemeral rivers in dry and drying environments globally.

KEYWORDS

Dryland rivers; hydro-ecological dynamics; landscape design strategies; design experimentation and testing; interdisciplinary design

Introduction

More than 50% of the world's population live near rivers and other freshwater bodies (Kummu, de Moel, Ward, & Varis, 2011). Historically, perennial dryland rivers played a key role in the development of important ancient civilisations, including Mesopotamia (Tigris and Euphrates), Pakistan and India (Indus), and Egypt (Nile) (Mithen & Black, 2011). These rivers now comprise a 'ribbon of life' in landscapes otherwise sparsely populated by plants and animals (Lyle, 1997). The number of intermittent or ephemeral rivers has risen globally due to urbanisation, industrialisation, excessive water extraction, and climate change (Palmer et al., 2008). In addition, an increasing number of perennial rivers now run dry before reaching the sea (Acuña et al., 2014; Hoekstra, Mekonnen, Chapagain, Mathews, & Richter, 2012).

Intermittent streams hold water during wet seasons of the year, and ephemeral channels only flow during and immediately after rain events. Intermittent and ephemeral streams have often been overlooked in conservation and restoration policies (Acuña et al., 2014; Leigh et al., 2016; Steward, von Schiller, Tockner, Marshall, & Bunn, 2012), and many consider them to have limited ecosystem services. However, several influential studies and reviews have shown the ecological significance of intermittent rivers and suggest a need to re-examine the potentials of these systems (Datry, Larned, & Tockner, 2014; Lake, 2003; Larned, Datry, Arcscott, & Tockner, 2010).

The ephemeral desert or dryland rivers in the Arabian Peninsula (known as *wadis*) have been generally understudied, with a few exceptions. For example Al-Obaid et al. (2016) highlighted the ecological values of wetlands in wadi systems in Saudi Arabia. Salih and Ghanem (2002), Şen (2008) and Shahin (2007) examined the hydrological characteristics of a number of wadis in the Arabian

Peninsula, looking at the quality and quantity of surface flows, surface evaporation, and ground-water recharge. However, in the design and built environment professions, little attention is paid to dryland rivers of the Arabian Peninsula, and yet their significance is coming to the foreground due to extensive urbanisation and the subsequent need for public open space. Currently, there are no studies that offer strategies or directions for urban designers and landscape architects to deal with hydro-ecological dynamics in ephemeral water systems.

In the drylands of the Arabian Peninsula, water resources are sensitive and vulnerable to human impacts, not only because of extreme aridity and increasing water scarcity but also because of human population stresses, ineffective environmental policies, and poor management (Michel, Pandya, Hasnain, Sticklor, & Panuganti, 2012; Sowers, 2011; Tortajada, 2014). Dryland waterways are mostly vulnerable in urban areas, because they are often perceived as drains to dispose of industrial waste, sewage, and urban run-off. In addition, the spread of modern 'Western style' public spaces (Moosavi, Makhzoumi, & Grose, 2016), such as parks, shopping malls, and waterfront resorts, have resulted in neglecting the wadis' potential as public spaces. In some cities, urban wadis are used as corridors for formal and informal vehicle traffic and live-stock movement (e.g. Muscat), or as sites for extracting sand and gravel. For example, in urban areas of major Arab cities, the fertile soil of dry riverbeds is excavated for use in construction and for replacing the soil where salinity prevents revegetation in large landscape projects (Steward et al., 2012).

Coupled with these pressures is the continuous human desire to be close to water edges in cities. The sporadic presence of water in drylands has generated specific landscape typologies or archetypes, such as the 'oasis' and 'refuge', embodying strong cultural connections for the desert inhabitants (Burmil, Danile, & Hetherington, 1999; Lyle, 1997). Wadis provide a microclimate of fresh and moist air that is usually a couple of degrees cooler than their surroundings (Şen, 2008). In the past, wadis provided social space and a natural refuge for desert inhabitants, and were considered important cultural landscapes.

A number of landscape architectural projects have recently emerged that aim to revive previous socio-cultural connections with urban and near-urban wadis. These projects have focused on reusing the riverbanks and, in some instances, the dry wadi bed, as linear public parks in response to the lack of public open spaces. Examples include the *Drâa Oasis Valley* and *Oued Fez* in Morocco, Wadi Hanifah in Riyadh, Saudi Arabia, the Jordan Valley in Jordan, and the Wadi Park Projects in Muscat, Oman.

The aim of this paper is twofold: first, to provide an understanding of the ecological and hydrological characteristics of wadis through the review of literature, and second, to identify important challenges and opportunities in contending with hydro-ecological dynamics of wadis in relation to their use as parklands. We report on an examination of multiple case studies of wadi restoration in Muscat and detail how designers, planners, engineers, and other decision makers operated to create public open space in these dryland landscapes.

Key characteristics of wadis

Definition and distribution

'Desert or dryland rivers' are often used interchangeably to describe rivers located in areas with less than 500 mm of annual rainfall, which are referred to as arid to semi-arid regions (Kingsford, 2006). Drylands, including hyper-arid (less than 25 mm per year rainfall), arid (25–200 mm), semi-arid, and dry sub-humid (200–500 mm) regions, occupy 50% of the globe's land area and support more than 20% of the world's population (Tooth, 2013, p. 613). According to Tooth (2013), 'dryland rivers', 'desert rivers', and 'arid-zone rivers' are commonly used to describe river systems that only flow infrequently and play a central role in landscape dynamics in drylands.

Wadi (the Arabic word for valley) is defined as the bed or valley of a stream that is usually dry except during the rainy seasons (Wheater & Al-Weshah, 2002). The wadis often act as oases suitable for

settlements and provide underground water resources for inhabitants. In urban areas, they often serve as natural drainage systems for seasonal flood water. Despite their important role in drylands of the Arab region, their dynamic hydrology is often poorly understood. It is important to note that dryland rivers can be found in all arid and semi-arid regions throughout the globe—examples include Colorado River (the major river of south-western United States and northern Mexico); the Syr Darya River running through Kyrgyzstan and Uzbekistan; and the Yellow River in China that often dries out before discharging in the sea (Changming & Shifeng, 2002; Liang, Ge, Wan, & Zhang, 2010). The focus here is on non-perennial dryland rivers (wadis) in the Arabian Peninsula.

Studies on dryland river morphologies suggest a variety of forms and typologies ranging from straight to meandering, or braided to dendritic patterns (Tooth, 2013; Wheeler & Al-Weshah, 2002). But the majority of wadis in flat desert areas show braided patterns due to the lack of continuous water flow, very low gradients, and episodic deposition of sediment. Nevertheless, it is common for one wadi or a geographical area to display more than one morphological pattern (see Figure 1).

A fluctuating hydrology

Wadis show high variability and unpredictability in their flow regimes (Shahin, 2007). Natural flooding is vital to the wadis' hydrological and ecological processes. Unfortunately, unpredictable flow patterns have resulted in extensive channelisation in urban areas to protect communities and surrounding infrastructures from flood risks. Hard engineering management strategies have led to the urban wadis' disconnection from underground water resources and groundwater depletion.

The wadi ecosystems undergo an imposing array of dynamic states and processes, which distinguishes them from perennial rivers. Extreme aridity and high evaporation levels countered by isolated and intense rainstorms result in shifting hydrological cycles, or 'boom and bust' behaviour (Bunn, Thoms, Hamilton, and Capon (2006). During or after a heavy rainstorm, the peak flood carried by a wadi can reach thousands of cubic metres per second, which can be extremely hazardous and result in flash flooding (Masoud, 2014; Shahin, 2007). The severity and intensity of flash floods can be heightened in urban areas, as the sun-baked hard surfaces of the built up catchment cannot absorb the rainwater from the sudden and short-lived storms (El-Baz, 2002, pp. 18–19). In addition, the sparse vegetation captures very little of the surface water, leaving limited room for infiltration and groundwater recharge.

While hydrological data on temperate rivers are widely available and used for flood modelling, such long-term data sets are not readily available for wadis, which makes their hydrological modelling difficult. A number of challenges and limitations in extracting robust hydrological data are identified, including the absence of base flow and high variability of hydrological regimes (Bull & Kirkby, 2002; Masoud, 2014), and the lack of adaptable measurement tools that can be used in desert environments. Alternative tools and site-specific methods are often required to obtain solid hydrological data in wadi systems.

The hydrology of wadis in the Arabian Peninsula varies considerably across similar climatic conditions. In a study by Shahin (2007) focusing on the quality and quantity of surface water, a number of wadis across the Arabian Peninsula were compared. Hydrological characteristics of wadis in Yemen, Oman, Saudi Arabia, and the United Arab Emirates were reviewed based on both measured and estimated rates of flow. Shahin (2007) concluded that the hydrological characteristics of these wadis are diverse. For example, while in Oman, wadis can flow continuously in the upper reaches and turn ephemeral when traversing the relatively flat inland areas of the country, in Saudi Arabia there are no perennial wadi flows, and surface run-off is very limited and irregular. In both countries, the wadis are commonly characterised by the flashy nature of their floods. This and similar studies demonstrate a need for site-specific approaches to data collection and the importance of long-term monitoring.



Figure 1. Comparison of different morphologies of wadis, showing the mountainous valleys of Wadi Shab in Oman (top images), and the low-gradient channel of Wadi Hanifah in rural areas near Riyadh in Saudi Arabia (bottom image). [Source: Top images by author, Muscat, 3 October 2013; bottom image courtesy of Arriyadh Development Authority, retrieved from <http://www.arriyadh.com/>, (accessed 10 June 2015)].

In addition to highly variable run-off rates in wadis, an important hydrological characteristic is their capacity to recharge underground alluvial aquifers. With increasing flash flood events driven by climate change and land use modification, water recharge to aquifers has been reduced drastically (Missimer, Drewes, Amy, Maliva, & Keller, 2012). Moreover, management strategies, such as constructing dams to retain flood flow, have proved to be ineffective. Missimer, Guo, Maliva, Rosas, & Jadoon (2015, p. 1) suggest that while management solutions such as using dams to store water can help reducing loss of run-off and recharging aquifers, a large part of the surface water (as high as 80%) in the wadi dam reservoirs is lost to evaporation due to the extreme heat. Alternative management strategies for retaining flood water and improving aquifer recharges in drylands include revegetation with native plants and landscape-based erosion control measures in the catchment areas.

Understanding the underlying hydrological processes peculiar to the wadis and their subsystems can help engineers and designers to develop more integrated and responsive design solutions. Clearly, an important consideration for designers in transforming wadis into parklands is dealing with flash flooding and dynamic changes.

A resilient ecology

Drylands are often thought to be unproductive places with no or very little support for ecological processes. However, many species have evolved to develop special adaptation strategies that allow them to endure harsh climatic conditions and variable water supply (Leigh et al., 2016). Evolved strategies for coping with sparse and unpredictable moisture include avoiding dry periods by taking refuge under sediments, rocks, and leaf litter or in remnant pools—known as ‘drought avoiders’—or enduring drought periods by variations in life cycle and growth rates—known as ‘drought endurers’ (Leigh et al., 2016; Price & Waser, 2007). Many drought avoiders have developed strategies to move to more favourable places during droughts (e.g. migratory birds and insects), while ‘drought endurers’ stay and remain physiologically active by storing water when it is available and using it sparingly during droughts (e.g. plants that are drought-deciduous or have dormant seeds). Datry et al. (2014, p. 231) suggest that natural drying–rewetting cycles serve as ‘important evolutionary cues that increase biological, physiological, and ecological trait diversity, which may in turn enhance adaptability of communities to future environmental change’. Preserving the dry-wet regimes in the wadis is, therefore, critical to their natural ecological processes.

Intermittent and ephemeral dryland rivers often support distinctive and fluctuating biodiversity (Steward et al., 2012). They embody the most diverse and dense vegetation communities found in the desert environments (Brinkmann, Patzelt, Dickhoefer, Schlecht, & Buerkert, 2009). Steward et al. (2012), Acuña et al. (2014) and Lake, Bond, and Reich (2017) have demonstrated the importance of understanding the ecological significance of intermittent waterways, and the critical interrelations between flow variability and riparian habitat. When flowing, these systems transfer nutrients and biota between the channel, the floodplain, and the riparian zone, laterally and longitudinally. Nutrient exchanges help support riparian vegetation and habitats. Therefore, building dams and other infrastructure that interfere with longitudinal connectivity can deplete the diversity and resilience of flora and fauna.

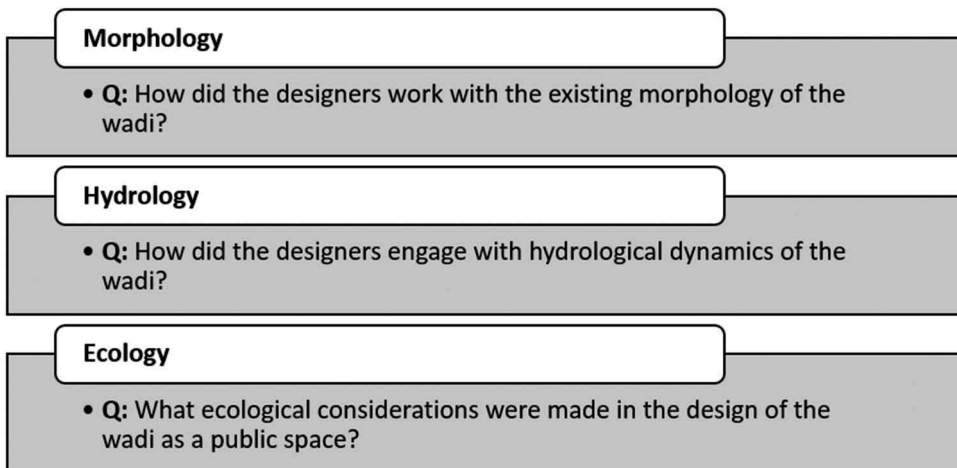
There is a strong relationship between natural fluxing conditions and biodiversity during transitions from rapid onset of flow into slower processes of shaping isolated pools and turning into dry channels. Longitudinal connectivity supports migration and navigation corridors for dispersal of biota in both dry and wet phases (Datry et al., 2014; Sánchez-Montoya, Moleón, Sánchez-Zapata, & Tockner, 2016; Steward et al., 2012). For example, isolated waterholes in the dry wadi beds often serve as stepping-stone habitats for animals, as they move along the stream to find water and food.

Understanding the distinctive biota and ecological processes and dynamics in dryland rivers underpins the importance of conserving the wadis’ ecosystems rather than solely considering their potential socio-economic benefits as new parks. Rehabilitation of wadis as public spaces requires engaging with hydro-ecological data, and this means working closely with ecologists, engineers, and environmental scientists in the design process.

Table 1. Summary of the main characteristics of urban and natural wadis in drylands.

Character	Key characteristics of wadis
Morphology	Varies from straight to braided, often braided due to limited flow and abundance of sediment in the desert
Hydrology	High variability Unpredictable flash floods Irregular dry-wet cycles, often ephemeral flows High groundwater levels and easy access to aquifers
Ecology	Flora and fauna with evolved adaptation strategies to endure/avoid droughts Diverse biota Rich and fertile soils Corridors for migration of biota including terrestrial vertebrates (mammals, birds, reptiles) Stepping stones with scattered vegetation and waterholes Refuges for some desert species in the dry phase Livestock grazing areas
Culture	Past: Corridors for migration of nomadic tribes Agricultural use Provision of water, food, and wood for desert inhabitants Terraced agriculture Oases for settlements Social gathering spaces and picnic ground Present: Used as car parks Shortcut roads Playgrounds for football and cricket Dumping ground for waste and rubbish Drains for urban run-off, sewage, and industrial waste

Table 1 summarises the key characteristics of wadi systems in natural and urban areas across four categories: Morphology, Hydrology, Ecology, and Culture. The case study analysis in this paper focuses on design responses to the morphological and hydro-ecological dynamics of wadis, and the key research questions are based on these three main characteristics listed in **Figure 2**. How the research design helped addressing these questions will be further elaborated upon in the following section. It is important to note that the contextual socio-cultural engagement in the proposed designs is outside of the scope of this paper.

**Figure 2.** Questions guiding the analysis of the projects based on the main characteristics of the wadis.

Methods

To address the research questions and to gain an understanding of the challenges of designing with morphological and hydro-ecological dynamics of wadis, we used a multiple case study method (Yin, 2002). The multiple case study method provides a full variety of evidence across different projects and contextual conditions, allowing for exploring a phenomenon (i.e. design) in its natural setting (Baxter & Jack, 2008). In this study, we focused on three recent wadi projects in urban areas of Muscat, Oman, as case studies. By examining the drivers of the selected wadi projects and their different processes of development, we identified the challenges and limitations the designers encountered in these projects and discussed the design responses in engaging with the wadis' key characteristics, which were discussed in the first part of this paper.

To investigate the case studies, we used multiple methods (see Figure 3) including discourse analysis (Paltridge, 2007), visual and textual analysis of the projects' documents including maps, reports, reviews, and drawings (Deming & Swaffield, 2011), as well as semi-structured interviews with the projects' designers, engineers (where available), and clients (Creswell, 2009). As described by Zeisel (1984, p. 137), focused interview is a powerful method that allows the researcher to 'find out in depth how people define a concrete situation, what they consider important about it, what effects they intended actions to have in the situation and how they feel about it'. In this study, 'design' is the main phenomenon at stake; therefore, the interview questions focused on the process of design. Overall, three designers involved in the selected wadi projects and the Chairman of Muscat Municipality as the client were interviewed. The interviews mainly took place in the designers' on-site offices, and in the Municipality of Muscat in Oman. Video calls and email conversations were used where the designers were not available for a face-to-face interview. The identity of the interviewees was kept confidential in accordance with informed consent agreements.

An 'interview schedule' was designed for the focused interviews (Berg & Lune, 2004), which included a mix of carefully worded questions and topic areas to allow a level of flexibility in the responses. The questions focused on unfolding the design brief and the project's aims, and the designers' understanding of the main characteristics of the wadi including working with the existing morphological features, engaging with ecological processes and dealing with hydro-ecological dynamics in design. A number of sub-questions were designed to answer the key research questions. These were mainly

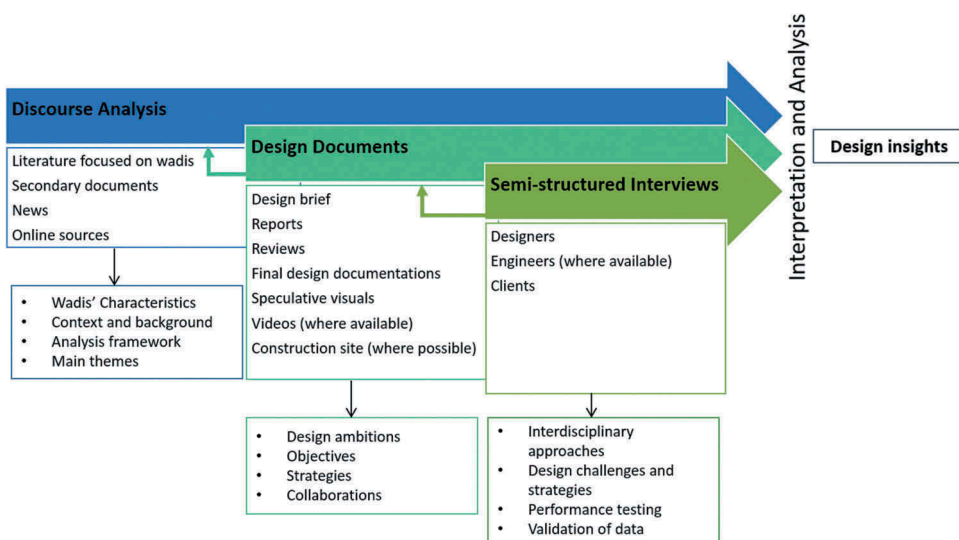


Figure 3. Diagram showing how each method was used to address the main research questions.

focused on the process of the design including the data and design methods used, the designers' understanding of the wadis' dynamics and dealing with uncertainties, and the interdisciplinary approach to design. An 'interview schedule' was designed for the focused interviews (Berg & Lune, 2004), which included a mix of carefully worded questions and topic areas to allow a level of flexibility in the responses. The questions focused on four main themes: the design brief and the project's aims, the designers' understanding of the main characteristics of the wadi including working with the existing morphological features, engaging with ecological processes, and dealing with hydro-ecological dynamics in design. A number of sub-questions were designed to answer the key research questions. These were mainly focused on the process of the design including the data and design methods used, the designers' understanding of the wadis' dynamics and dealing with uncertainties, and the interdisciplinary approach to design. The interview with the client helped with the triangulation of data collected and gaining a better understanding of the requirements of the projects (see Tables A1 and A2 in Appendix A for a list of interview questions). The interviews were transcribed and interpreted by systematic analysis of emerging themes and coding (Creswell, 2009).

Using a multi-method approach allowed for triangulation of data sources (Baxter & Jack, 2008; Berg & Lune, 2004). The data collected from relevant discourses and design documents were interpreted and validated against the data drawn from the interviews. This comparison revealed interesting insights about how design practice is often represented in public documents and how practice is undertaken in reality; in other words, how design representations differ from the true stories of design, and the absence of challenges, complications, and failures from mainstream project-based discourses (Moore, 2010).

Study area and case studies

Three wadis in Muscat, Oman, were selected for the purpose of this study as cases of dryland wadi projects. Muscat, the capital of Oman, is located northeast of the country on the edge of the Arabian Sea along the Gulf of Oman. The city has a unique urban morphology, stretching between the coastline and the dark mountain ranges of Western Al Hajar Mountains, which allows the harnessing of most of the seasonal storm water drains at the cost of occasional flooding.

The condition of wadis in the urban areas of Muscat has been negatively impacted by urbanisation (Al-Rawas, Valeo, Khan, & Al-Hafeedh, 2015). Since 2010, the Municipality of Muscat has initiated a number of projects to reverse the current situation of the wadis by highlighting their natural and cultural importance, and emphasising their social values. According to the authors' interviews with the Muscat Municipality's former chairman in 2013, the wadi projects emerged to showcase their role as 'the city's landmarks and emphasise their potential for providing public amenities'.

Extreme flooding in Muscat is the major challenge in designing the wadis as public parks. For instance in the last decade, Muscat and its wadis have been affected by several flash floods, including cyclone Gonu in 2007, and severe flood events in 2008, 2009, 2014, and 2015 (EUMETSAT, 2017). According to climate change predictions, Oman is expected to receive less annual rainfall by 2040; however, the number of extreme rainfall events is predicted to increase and summer monsoons are likely to intensify (Al-Charabi & Al-Yahya, 2013). Despite the Municipality's claims for prioritising issues of flooding in the wadi projects, there are limited considerations for future flood mitigation in the current and ongoing projects, and the main focus appears to be providing public amenities and increased land values.

Unlike other Gulf cities in the Arabian Peninsula, Muscat has retained its traditional charm by implementing particular building and planning regulations. However, a critical examination of the current state of the city reveals an extensive lack of public open spaces and human-scale amenities for pedestrians. Rejuvenating the wadis, according to city officials, is part of the vision for moving towards a 'human city' or a 'city for the people'. This vision is highly influenced by the Danish Architect, Jan Gehl's visit to Muscat in 2010. Following Gehl's visit to Muscat, an ambitious project dubbed as 'Majestic Muscat' was initiated by the Municipality. Divided into 24 projects, the Majestic Muscat aimed to



Figure 4. Location of Wadi Al Kabir, Wadi Adai, and Wadi Azeiba and their catchments in Muscat Basin, and Oman.
[Source: S. Moosavi].

provide public open spaces for recreation and entertainment purposes for residents and visitors. The projects included revitalising several wadis and their surrounding districts.

For the purpose of this study, three recent and ongoing projects were selected: Wadi Al Kabir, Wadi Adai, and Wadi Azeiba. The selected projects embody different scales of intervention and reveal a spectrum of design approaches to revitalisation. These three projects are located in different districts in Muscat, stretching from East to West along the coast of the Gulf of Oman. [Figure 4](#) shows the location and the approximate size of the selected wadis.

Wadi adai

Wadi Adai is one of the main wadis located south of Muscat. It has the largest catchment area of 380 km² in Oman (Soliman, 2010). The wadi carries a large amount of run-off during rainfall events, and

this has resulted in several hazardous flash floods in recent decades. There are future plans to mitigate the flood risks by building several dams upstream of the wadi, of which two are currently in progress. The dams might offer a short-term protection from flooding; however, in addition to high rates of free-surface evaporation due to extreme heat, dams have negative impacts on longitudinal connectivity and biodiversity, and they may not enhance the resilience of the city to floods in the long term.

The main aim in the rehabilitation of Wadi Adai, as noted in the initial design brief, was to create cultural activities adjacent to the wadi and to generate a 'sense of local pride and social ownership' for the citizens towards these spaces. Various urban plazas along the wadi were proposed as points of interest, connected through a network of pedestrian trails and cycling paths in the wadi. The provision of a pedestrian bridge over a section of the wadi was the main catalyst for the project's development. The design team, however, extended the brief by proposing walking and seating areas, plazas, and terraced embankments that make the wadi more accessible and permeable to the urbanised neighbourhood.

Wadi al kabir

Wadi Al Kabir is one of the minor wadis in Muscat's Basin. It has a smaller catchment area compared with other wadis in Muscat; therefore, the channel has a lower run-off capacity. The wadi passes through *Ruwi*, the commercial hub and main business district of Muscat. Ruwi sits in the valley bisected by Wadi Al Kabir, bounded by mountains to the east and west. It is centrally located at the historic district of *Mutrah* (the old harbour district), the *Al Khuwair* Ministry and Embassy precinct, and the *Al Alam* Palace. East of Wadi Al Kabir is the Central Business District (CBD) that includes commercial buildings predominantly between 6 and 12 stories in height. In the West of Wadi Al Kabir, there is an eclectic mix of smaller scale commercial buildings, retail strips with residential apartments above, public buildings including schools, mosques, clinics, and residential apartments. Currently, the wadi channel is an empty space disconnected from the neighbourhood with major roads running along both sides. As part of the Majestic Muscat project, Ruwi's masterplan was developed to identify frameworks and strategies under which the whole district can be rejuvenated into a 'desirable location' for citizens 'to live, work and recreate' (Project Architecture Pty. Ltd., 2010).

The design proposal for rehabilitating Wadi Al Kabir includes a one-kilometre linear park inside the dry wadi channel, with pedestrian trails, two cricket and football fields, two pedestrian bridges, and narrow water channels running inside the channel inspired by the traditional *Aflaj* systems, which are irrigation channels used in Oman for agriculture and domestic use as early as 2500 BC (Preston, Parker, Walkington, Leng, & Hodson, 2012).

Wadi al azeiba

Wadi Al Azeiba (also known as *Udhaybah*) Park is the first constructed and completed wadi park of the new Landscape Strategy Plan for Muscat (the Majestic Muscat Project). Situated in Udhaybah, west of the city of Muscat and along the main airport access road, this wadi runs through a low-rise residential neighbourhood between Sultan Al Qaboos Highway and the Gulf of Oman. Udhaybah district was originally a small tribal village with wells and date palms. In the 1950s, it was chosen as the headquarters of an oil company. Later in the 1970s, it was colonised by industrial plants and gradually transformed into a new residential area (Peterson, 2007).

Wadi Azeiba was previously used as a rubbish dump and acted as a storm water drain, until a landscape design firm was commissioned in 2010 to transform the site and its surroundings and connect the neighbourhood to the wadi. The proposal aimed at turning the empty wadi into a linear park with public promenades and walk-ways. Phase one of the project was finished in 2012, and a segment of the wadi has been transformed into a public park for those who would like to have a brief escape to a more natural setting (see [Figure 5](#)).



Figure 5. Sequential time-lapse Google imagery of changes in Wadi Azeiba, from 2009 to 2015. Phase one of the project (the southern section of the wadi) was completed in 2012. [Source: Adapted from Google Earth Copyright 2017, DigitalGlobe].

Results

To investigate the design of the three case studies, three key research questions were used to frame the analysis focusing on the wadis' morphology, hydrology, and ecology (see Figure 2). The examination of design documentations and the analysis of interviews with the designers and clients revealed different objectives and ambitions across selected wadi rehabilitation projects, from socio-economic to more ecological-driven goals. Different design ambitions led to a spectrum of design approaches in dealing with the wadis' hydro-ecological dynamic, which will be further elaborated upon.

In the Wadi Al Adai project, the designers proposed descending terraces, instead of the existing vertical concrete channel, to soften the edges and connect the urban areas to the wadi. In order to mitigate and reduce the risks of flash flooding, the pedestrian bridge was designed as a multi-functional landscape element. While the bridge could serve as a connector and a gathering space for people to reconnect to the wadi at different levels, a descending ramp was designed in the middle of the bridge allowing for quick evacuation from the wadi bed, in case there is a sudden flash flood. This shows the designers' awareness of the sporadic nature of the wadi. The lights on the bridge and the embankments were designed to create a spectacular nightscape with lit pathways highlighting the presence of the wadi and its features at night.

In response to improving the ecological conditions of the wadi, three tear-drop-shaped islands with native vegetation were proposed inside the wadi channel (see Figure 6). These islands mimic some of the existing landforms that naturally occur in the wadi bed through deposition (e.g. mid-channel bars that often form in ephemeral braided river systems). In addition to the recreational role of the vegetative islands, they were proposed to slow down flood flow, enable water infiltration and groundwater discharge, create terrestrial habitat, allow sedimentation, and mitigate erosion. Despite considering reinforcement of the structures, the designers noted that they were unsure of the islands' endurance. They speculated two different possible futures: decay and disappearance with erosion, and natural growth

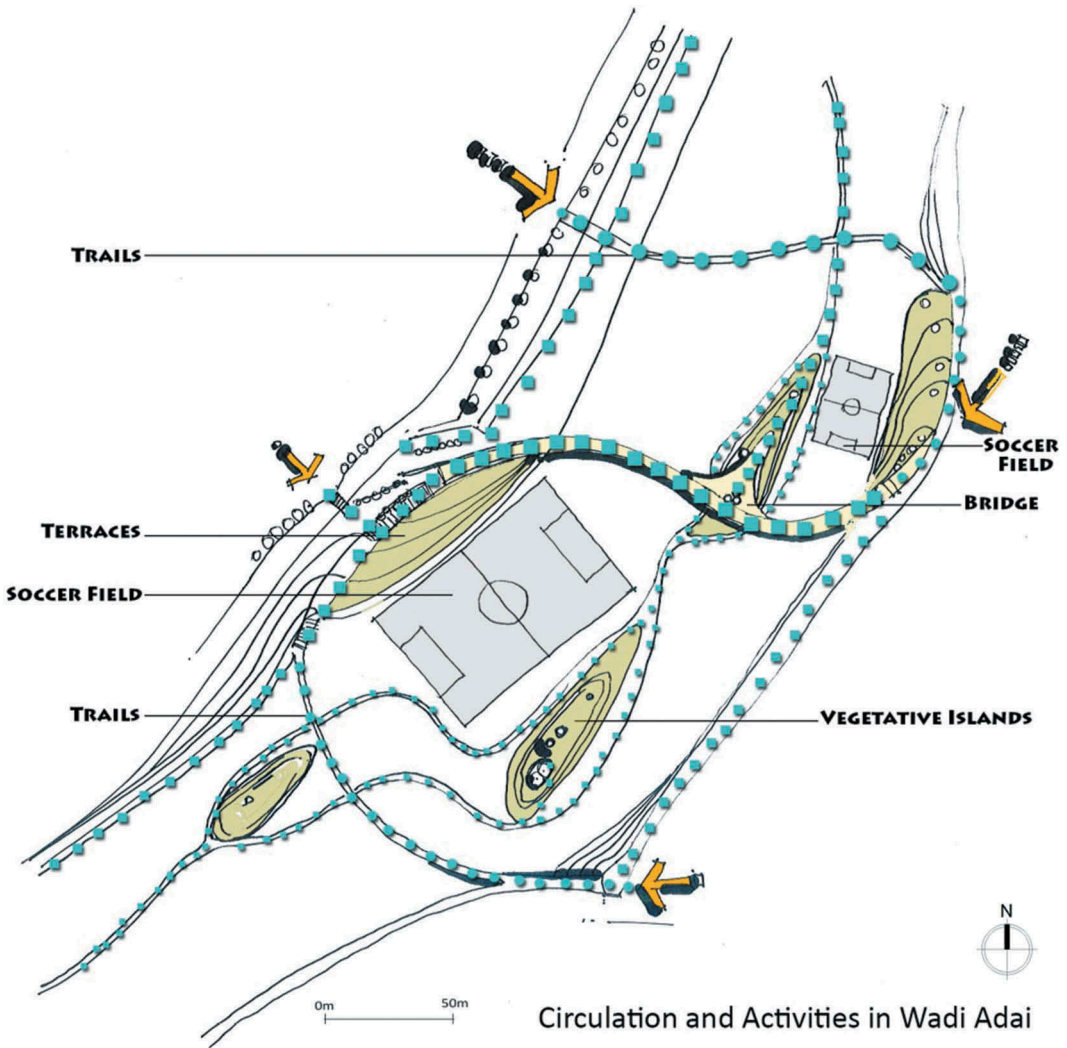


Figure 6. This diagram shows the three vegetative islands, terraced embankments on both sides, and the descending bridge. The configuration of spaces and the curving circulation paths are aligned with the bending morphology of the wadi, and the water flow direction. [Source: drawn by S. Moosavi].

as a result of deposition and accumulation of sediments over time. This conceptualisation shows the designers' sensibility towards engaging with natural dynamics in design and their aim for a performative landscape that is flexible to change. However, the design team could have used flow simulation models to test the stability of the islands with different flood scenarios to ensure their design is adaptive.

The construction of the pedestrian bridge and embankments were completed in 2013 (Figure 7). Since then, the designed spaces have not been affected by a major flood event, and the performance of the proposed landscape is yet to be further examined.

Unlike the design proposal for Wadi Adai, in the Wadi Al Kabir project there is limited evidence that suggests an engagement with the hydrological dynamics of the wadi. The analysis of the design documents and interviews suggested a strong emphasis on enhancing physical and visual connectivity in the Ruwi district by creating pedestrian access and green spaces inside and along the wadi. In the design brief, particular attention was given to achieving high revenues on land values in the neighbourhood through visual enhancement and the greening of the wadi. For example, the design proposal



Figure 7. Top image, Wadi Adai in its dry state [image courtesy of Batco Engineering group, Copyright 2017 by Batco Engineering Group, reprinted with permission, retrieved from <http://www.batco-group.com>, (accessed 3 July 2018)]; bottom image showing the wadi in its wet phase and the flooded construction site; the upper stepped terraces can still be used in wet conditions. [Source: Courtesy of Snøhetta, Copyright 2013 provided by Kent Horne, reprinted with permission].

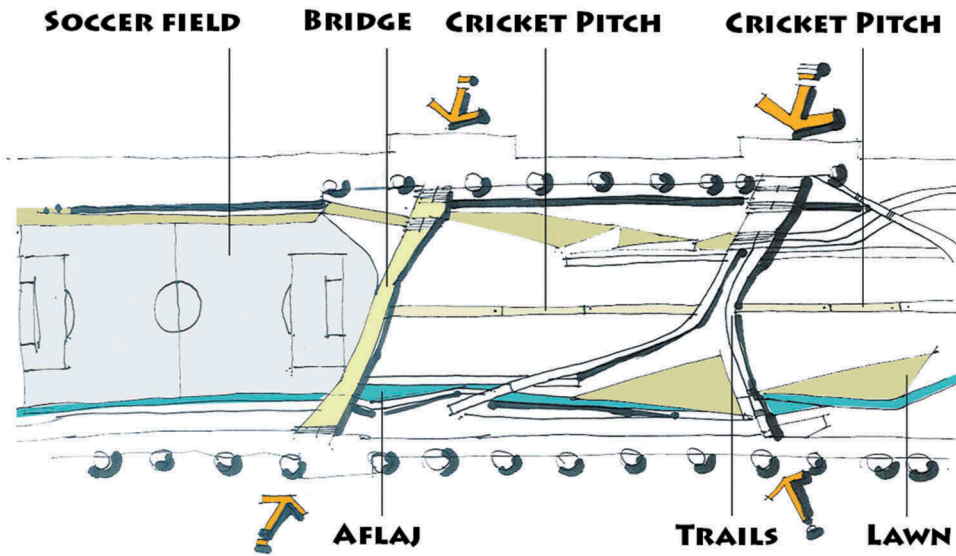
suggests the use of hard edges and extensive turf surfaces inside the wadi bed, which can be damaged by extreme flooding (Figure 8). Overall, the design focused on providing access and creating pedestrian trails and playgrounds inside the wadi bed (Figure 9), and limited changes were proposed for modifying the existing concrete channel and hard edges of the wadi, and improving riparian connectivity.

When asked about the engagement with the wadi's ecology in the proposed design, the designers explained that they have not considered a detailed 'plant selection' at that stage of the project. This comment suggests reducing ecology and its broad field of application to 'plant selection' and shows limited consideration of the wadi as an ecosystem in its broader context and the lack of attention to improve the wadi's ecological performance as an important ecosystem for biota. The designers blamed the 'confined site of intervention' for restricting them to engage with the larger context.

Limited engagement with temporal changes and ecological processes in dry and wet phases also suggested the absence of ecologists and environmental scientists in the design process, which was confirmed by the designer in the interviews. Furthermore, there was a clear disconnection between the role of the engineers' and the designers in the project. The engineers were solely responsible for designing the structure of the pedestrian bridges. They used hydrological data and modelling for calculating the stability of the structures and the ensuing effects of scouring. The structural brief prepared by the engineers included the technicalities of constructing the pedestrian bridge and the model used to test structural integrity, but it did not indicate how hydrological data were used to design



Figure 8. Aerial image of the location and proposed design for Wadi Al Kabir Park, showing the playgrounds and trails inside the wadi bed, surrounded by a highly urbanised area in Ruwi, Muscat, Oman. [Source: From Ruwi's Masterplan 2010, Copyright 2010 by Project Australia Pty, Ltd, reprinted with permission].



Overall Siteplan of Wadi Al Kabir

Figure 9. Diagrammatic drawing of the design of Wadi Al Kabir, showing the circulation paths, playground, and entry point to the wadi. [Source: drawn by S. Moosavi].

the embankments and other elements. According to in-person interviews with the chief designer, hydrological data such as velocity, flow, and flood mitigation measures were not readily available for informing the design of the embankments, landscape elements, and recreational spaces. The Wadi Al Kabir project has not been implemented and has remained at the feasibility phase since 2010.

Among the case studies examined, Wadi Azeiba is the only fully built project to date. The design proposal for turning Wadi Azeiba into a linear park demonstrates an example of creating capacity for accommodating water dynamics and ecological flux within a confined urban site. The design's adaptive capacity to deal with episodic floods is achieved by allowing the site to flood in the lower part of the wadi bed, using minimal intervention and drought-tolerant plants that can survive both long periods of droughts, and short-term waterlogging. The upper part of the wadi is designed with elements such as benches, pergolas, and ornamental plants, of which some are non-natives. The edges of the wadi are lined with gabions and terraces planted with vegetation, allowing for water infiltration and groundwater recharge.

Importantly, the designers did not envisage a fixed future for the landscape; instead, the wadi was designed considering temporal changes occurring in the wadi park (as demonstrated in [Figure 10](#)). This project shows that within a confined scale—almost similar to the site scale in Wadi Al Kabir—there are opportunities for integrating dynamic changes and working with water, not as a destructive element to be avoided, but as a system to be intertwined with public spaces, creating a hybrid space that is occasionally flooded. In this project, water flux and the dynamic ecology associated with hydrological changes have been integrated in the design of spaces; the park is in an ongoing process of evolving and becoming.

There are still unanswered questions as to whether and how the space will respond to major flash flooding, and to what extent the space carries the capacity to accommodate more severe floods without drastic spatial changes. It also remains unclear how site-specific data, such as flood data, or modelling techniques were used in the design. Additionally, creating a hybrid space that floods requires ongoing maintenance compared with a conventional park. Nevertheless, Wadi Azeiba project provides an example for conceptualising urban wadis as hybrid landscapes with capacities for accommodating water dynamics and allowing for emerging ecologies, while acting as a socio-cultural destination.

The following table summarises the findings from the interviews and the analysis of the design proposals showing how the designers in each project engaged with the key characteristics of wadis, focusing on morphology, hydrology, and ecology (see [Table 2](#)).

Table 2. Design responses to the morphology, hydrology, and ecology of wadi systems.

	Wadi Al Kabir	Wadi Adai	Wadi Azeiba
Size	A stretch of 2 km along the wadi	Site boundaries were not clear, less than 1 km long	Phase 1 of the project approximately 300 m long, Phase 2 more than 1 km
Morphology	Limited changes to the existing straight channel, designing within the concrete channel with limited modifications	Consideration of existing spatial morphologies downstream, mimicking natural forms in creating vegetative islands and terraces with organic forms aligned with the hydrodynamics of water flow	Followed the existing shape of the wadi, but proposed soft edges with vegetation and gabions
Hydrology	Designed the banks in two different levels for use according to water presence, limited consideration of the flood force inside the wadi channel with no evacuation measures	Minimal intervention inside the wadi bed, design of embankments and seating areas in the upper level, descending bridge for quick evacuation in the wet phase	Allowed the lower part of the wadi to flood, accommodating water fluctuation, used pervious surfaces and plants to increase infiltration and reduce erosion
Ecology	Limited consideration of the changing ecology in dry and wet phases, use of exotic plants and turf surfaces inside the wadi which can be water intensive	Consideration of plant succession on the proposed vegetative islands, working with natural processes and temporal changes	Use of drought tolerant native and exotic plants that can withstand water logging, some exotic plants require maintenance, allowing succession of plants over time and the space to adapt to dry-wet cycles



Figure 10. Top photo: Wadi Azeiba Park partially flooded after heavy rainfall in April 2012. [Source: Photo taken by GMR on 19 April 2012, Copyright 2012 by GMR, reprinted with permission, retrieved from www.Panoramio.com, (accessed 4 December 2013)]; Bottom photo: The same view shows the wadi in its dry phase. Plants such as rushes, sedges, and other drought tolerant plants that can tolerate short-term flooding are used in the wadi bed; [Source: Photo S. Moosavi, 3 October 2013].

Discussion

The results of the analysis showed that the major design challenge across all three wadi projects is speculating how hydro-ecological changes might affect the wadi parks over time, and how the design can accommodate some of these changes. Three design strategies including the importance of spatial-temporal scales, interdisciplinary approaches to design, and performance testing were identified through a cross-analysis of the projects.

The analysis showed that with the sporadic nature of the wadi systems, it is important to consider the site of intervention in its broader hydrological, ecological, and temporal context and

as part of a system with visible and invisible human and natural processes. This includes a multi-scalar understanding of the catchment processes and spatial forms beyond the site of focus, and considering the impact of design interventions on the system over time. This can be challenging for designers who are often given a limited time frame for project delivery and a confined site area.

The designers' approach in Wadi Adai went beyond the initial design brief (which mainly focused on delivering a pedestrian bridge). The designers' proposal of terraced embankments with soft edges and vegetative islands for ecological improvement shows the role of designers in understanding the site as part of a larger system and redesigning the brief accordingly. In Wadi Azeiba, attention to systems approaches and temporality is evidenced by the capacity of the wadi park in accommodating temporal flooding.

Working across disciplinary groups, including engineering, science, ecology, planning, design, and anthropology can contribute to a holistic understanding of landscape systems and innovative design outcomes (Schwartz, 2013). Across all three projects, there was a clear disconnection between the work of the engineers and the designers, and the absence of ecologists. Designers can benefit from working closely with engineers and ecologists to understand the implications of design interventions on hydro-ecological processes and to enable them to better mitigate the risks associated with flooding with adaptive solutions. The modelling tools the engineers used in Wadi Al Kabir to test the performance of the bridges against dynamic forces provide an example of a data-driven approach to design for achieving better performance. The engineers' testing methods could have, however, helped the designers to make more responsive decisions for the design of the embankments and other landscape elements.

An interdisciplinary approach to design closely relates to the final strategy suggested here, which is iterative design explorations using safe-to-fail testing and modelling techniques, such as physical and digital prototyping, for achieving performative design outcomes with higher reliability and flexibility (Grose, 2014; Reed & Lister, 2014; Walliss & Rahmann, 2016). The analysis of three wadi projects in Muscat revealed the lack of integrative design approaches and highlighted the important role of engineers in sharing their scenario testing methods and knowledge of 'safe-to-fail' experimentations with designers (Ahern, 2013; Lister, 2007). Safe-to-fail design experiments can be used to reduce the risk of failure when working with dynamic systems and provide learning opportunities for designers (Lister, 2007, p. 46). Design experimentation and performative testing are increasingly becoming an integral part of landscape architecture, helping designers to work with site-specific data and test different scenarios against agencies of change (Grose, 2017, pp. 173–180; Moosavi, 2018).

Understanding and acknowledging existing limitations and challenges in working with dynamic landscapes that embody uncertainties reveal future research avenues. As discussed earlier, limitations in working with wadi systems in the Arabian Peninsula include the availability of accurate and up-to-date hydrological and ecological data. These limitations call for further scientific research to build on an emerging body of work on dryland wadis.

This research focused on how hydro-ecological dynamics were integrated in the design process as opposed to examining the socio-ecological outcomes. This suggests areas of further research on the performance of built wadis as parklands after the projects are completed. The investigation of the design of three wadi projects in Muscat, Oman, raised important questions: How would the new wadi parks perform in extreme flood events, and who would be responsible for ongoing management and monitoring of the wadis' performance? In addition, ecological monitoring and post-occupancy evaluation is required to test how the new wadi parks help to improve the local ecosystem. For example, there are opportunities for species sampling before and after the rehabilitation, which can provide important lessons for designers working on future projects. A longitudinal investigation of built projects would further reveal valuable knowledge in landscape practice.

Finally, the projects examined here do not reveal best practice techniques for designing wadi parks. But the focus of the authorities in Oman on the country's local landscape provides important alternatives to western-style public spaces for other Gulf countries in the Arabian Peninsula. The challenge for decision

makers and practitioners, however, lies in directing these initiatives towards supporting, protecting, and enhancing the ecological performance and long-term resilience of the wadi parks in the face of extreme climate events.

Conclusion

The key characteristics of wadis, including variability and unpredictability of flash floods, absence of water over long time spans, and the fluxing of hydrological and ecological processes, pose great challenges to landscape architects and engineers engaged in the rehabilitation and design of wadis in the Arabian Peninsula. Three wadi projects in the city of Muscat, Oman, examined here revealed the need for science-based, data-driven, and interdisciplinary methods to deal with the spatial and temporal characteristics of wadis. These projects also highlight core design challenges and opportunities for dealing with dynamics and uncertainty in a fluxing world, suggesting the need for designs that have an adaptive capacity to accommodate change. In the first instance, with an increasing global temperature and the climate changing at a rapid pace, approaches to dryland systems amid increased urbanisation are likely to lead the way in informing global design practices in many regions.

Acknowledgements

The authors would like to express their gratitude to Dr Jillian Walliss for her insightful comments and valuable guidance during the research, and the generosity of the international designers, and key informants from the Municipality of Muscat who participated in the interviews.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This study was funded by an Australian Postgraduate Award (APA) and travel grants from the University of Melbourne.

ORCID

Sareh Moosavi  <http://orcid.org/0000-0002-4819-2772>

References

- Acuña, V., Datry, T., Marshall, J. C., Barceló, D., Dahm, C. N., Ginebreda, A., ... Palmer, M. A. (2014). Why should we care about temporary waterways? *Science*, 343(6175), 1080–1081.
- Ahern, J. (2013). Urban landscape sustainability and resilience: The promise and challenges of integrating ecology with urban planning and design. *Landscape Ecology*, (6), 1203. doi:10.1007/s10980-012-9799-z
- Al-Charabi, Y., & Al-Yahya, S. (2013). Projection of future changes in rainfall and temperature patterns in Oman. *Journal of Earth Science & Climatic Change*, 4(5), 154–161.
- Al-Obaid, S., Samraoui, B., Thomas, J., El-Serehy, H. A., Alfarhan, A. H., Schneider, W., & O'Connell, M. (2016). An overview of wetlands of Saudi Arabia: Values, threats, and perspectives. *Ambio*, 1–11. doi:10.1007/s13280-016-0807-4
- Al-Rawas, G. A., Valeo, C., Khan, U. T., & Al-Hafeedh, O. H. (2015). Effects of urban form on wadi flow frequency analysis in the wadi aday watershed in Muscat, Oman. *Urban Water Journal*, 12(4), 263–274.
- Baxter, P., & Jack, S. (2008). Qualitative case study methodology: Study design and implementation for novice researchers. *The Qualitative Report*, 13(4), 544–559.
- Berg, B. L., & Lune, H. (2004). *Qualitative research methods for the social sciences* (5th ed.). Boston: Pearson.
- Brinkmann, K., Patzelt, A., Dickhoefer, U., Schlecht, E., & Buerkert, A. (2009). Vegetation patterns and diversity along an altitudinal and a grazing gradient in the Jabal al Akhdar mountain range of northern Oman. *Journal of Arid Environments*, 73(11), 1035–1045.

- Bull, L. J., & Kirkby, M. J. (2002). Dryland river characteristics and concepts. In L. J. Bull & M. J. Kirkby (Eds.), *Dryland rivers: Hydrology and geomorphology of semi-arid channels* (pp. 3–16). Chichester: John Wiley & Sons.
- Bunn, S. E., Thoms, M. C., Hamilton, S. K., & Capon, S. J. (2006). Flow variability in dryland rivers: Boom, bust and the bits in between. *River Research and Applications*, 22(2), 179–186.
- Burmil, S., Danile, T., & Hetherington, J. D. (1999). Human values and perceptions of water in arid landscapes. *Landscape and Urban Planning*, 44(2–3), 99. Retrieved from <http://sfx.unimelb.hosted.exlibrisgroup.com/sfx/cl41?sid=google&auinit=S&aulast=Burmil&atitle=Human%20values%20and%20perceptions%20of%20water%20in%20arid%20landscapes&id=doi%3A10.1016%2FS0169-2046%2899%2900007-9&title=Landscape%20and%20urban%20planning&volume=44&issue=2&date=1999&spage=99&issn=0169-2046>
- Changming, L., & Shifeng, Z. (2002). Drying up of the yellow river: Its impacts and counter-measures. *Mitigation and Adaptation Strategies for Global Change*, 7(3), 203–214.
- Creswell, J. W. (2009). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). London: SAGE Publications.
- Datry, T., Larned, S. T., & Tockner, K. (2014). Intermittent rivers: A challenge for freshwater ecology. *BioScience*, 64(3), 229–235.
- Deming, E. M., & Swaffield, S. R. (2011). *Landscape architectural research: Inquiry, strategy, design*. Chichester: John Wiley & Sons.
- El-Baz, F. (2002). *Wadis of Oman: Satellite image Atlas*. Muscat, Sultanate of Oman: Office of The Advisor to His Majesty The Sultan for Cultural Affairs.
- EUMETSAT. (2017). Oman flood data. Retrieved Date from <http://www.eumetsat.in>.
- Grose, M. (2014). Gaps and futures in working between ecology and design for constructed ecologies. *Landscape and Urban Planning*, 132, 69–78. Retrieved from <http://sfx.unimelb.hosted.exlibrisgroup.com/sfx/cl41?sid=google&auinit=MJ&aulast=Grose&atitle=Gaps%20and%20futures%20in%20working%20between%20ecology%20and%20design%20for%20constructed%20ecologies&id=doi%3A10.1016%2Fj.landurbplan.2014.08.011&title=Landscape%20and%20urban%20planning&volume=132&date=2014&spage=69&issn=0169-2046>
- Grose, M. (2017). *Constructed ecologies: Critical reflections on ecology with design*. New York: Routledge.
- Hoekstra, A. Y., Mekonnen, M. M., Chapagain, A. K., Mathews, R. E., & Richter, B. D. (2012). Global monthly water scarcity: Blue water footprints versus blue water availability. *PloS one*, 7(2), 1–9.
- Kingsford, R. T. (2006). *Ecology of desert rivers*. New York: Cambridge University press.
- Kummu, M., de Moel, H., Ward, P. J., & Varis, O. (2011). How close do we live to water? A global analysis of population distance to freshwater bodies. *PloS one*, 6(6). doi:10.1371/journal.pone.0020578
- Lake, P. S. (2003). Ecological effects of perturbation by drought in flowing waters. *Freshwater Biology*, 48(7), 1161–1172.
- Lake, P. S., Bond, N., & Reich, P. (2017). Restoration ecology of intermittent rivers and ephemeral streams. In T. Datry, N. Bonada, & A. J. Boulton (Eds.), *Intermittent rivers and ephemeral streams: Ecology and management* (pp. 509–533). London, United Kingdom: Academic Press.
- Larned, S. T., Datry, T., Arscott, D. B., & Tockner, K. (2010). Emerging concepts in temporary-river ecology. *FWB Freshwater Biology*, 55(4), 717–738.
- Leigh, C., Boulton, A. J., Courtwright, J. L., Fritz, K., May, C. L., Walker, R. H., & Datry, T. (2016). Ecological research and management of intermittent rivers. *An Historical Review and Future Directions*. *Freshwater Biology*, (61), 1181–1199. doi:10.1111/fwb.12646
- Liang, S., Ge, S., Wan, L., & Zhang, J. (2010). Can climate change cause the yellow river to dry up? *Water Resources Research*, 46(2), 1–8.
- Lister, N. M. (2007). Sustainable large parks: Ecological design or designer ecology? In J. Czerniak & G. Hargreaves (Eds.), *Large Parks* (pp. 35–57). New York: Princeton Architectural Press.
- Lyle, J. T. (1997) *Archetypes in the arid landscape*. Paper presented at the Sustainable landscape design in arid climates: Proceedings of a symposium jointly organised by the Aga Khan Trust for Culture and Studies in Landscape Architecture, Dumbarton Oaks, Washington D.C.
- Masoud, M. H. (2014). Rainfall-runoff modeling of ungauged wadis in arid environments (case study Wadi Rabigh—Saudi Arabia). *Arabian Journal of Geosciences*, 8(5), 2587–2606.
- Michel, D., Pandya, A., Hasnain, S. I., Sticklor, R., & Panuganti, S. (2012). *Water challenges and cooperative response in the Middle East and North Africa*. Washington, DC: The Saban Center for Middle East Policy at Brookings. <http://www.brookings.edu/research/papers/2012/11/water-security-middle-east-iwf>
- Missimer, T. M., Drewes, J. E., Amy, G., Maliva, R. G., & Keller, S. (2012). Restoration of wadi aquifers by artificial recharge with treated waste water. *Groundwater*, 50(4), 514–527.
- Missimer, T. M., Guo, W., Maliva, R. G., Rosas, J., & Jadoon, K. Z. (2015). Enhancement of wadi recharge using dams coupled with aquifer storage and recovery wells. *Environmental Earth Sciences*, 73(12), 7723–7731.
- Mithen, S., & Black, E. (2011). *Water, life and civilisation: Climate, environment, and society in the Jordan Valley*. New York: Cambridge University Press.
- Moore, K. (2010). *Overlooking the visual: Demystifying the art of design*. London: Routledge.

- Moosavi, S. (2018). Time, trial and thresholds: Unfolding the iterative nature of design in a dryland river rehabilitation. *Journal of Landscape Architecture*, 13(1), 22–35.
- Moosavi, S., Makhzoumi, J., & Grose, M. (2016). Landscape practice in the Middle East between local and global aspirations. *Landscape Research*, 3(41), 265–278.
- Palmer, M. A., Reidy Liermann, C. A., Nilsson, C., Flörke, M., Alcamo, J., Lake, P. S., & Bond, N. (2008). Climate change and the world's river basins: Anticipating management options. *Frontiers in Ecology and the Environment*, 6(2), 81–89.
- Paltridge, B. (2007). *Discourse analysis: An introduction*. London: Bloomsbury.
- Peterson, J. (2007). *Historical Muscat: An illustrated guide and gazetteer*. Leiden; Boston: Brill.
- Preston, G. W., Parker, A. G., Walkington, H., Leng, M. J., & Hodson, M. J. (2012). From nomadic herder-hunters to sedentary farmers: The relationship between climate change and ancient subsistence strategies in south-eastern Arabia. *Journal of Arid Environments*, 86, 122–130.
- Price, M., & Waser, N. (2007). Where rivers run dry or ten feet high: Variation and predictability matter more than averages for desert ecosystems. *Aridlands Newsletter*. Retrieved from <https://cals.arizona.edu/OALS/ALN/aln59/price.html>
- Project Architecture Pty Ltd. (2010). *Ruwi masterplan: Key sites - concept plans*. Sydney, Australia
- Reed, C., & Lister, N. M. (2014). *Projective ecologies*. Cambridge; New York: Harvard University Graduate School of Design, Actar.
- Salih, A. M. A., & Ghanem, A. H. M. (2002). Sustainable management of wadi systems: IHP regional network on wadi hydrology in the Arab region. In H. Wheeler & R. A. Al-Weshah (Eds.), *Hydrology of wadi systems* (pp. 145–159). Paris: UNESCO.
- Sánchez-Montoya, M. M., Moleón, M., Sánchez-Zapata, J. A., & Tockner, K. (2016). Dry riverbeds: Corridors for terrestrial vertebrates. *Ecosphere*, 7(10), 1–10.
- Schwartz, J. (2013). The sensuality of the engineer. In C. Girot, A. Freytag, A. Kirchengast, & D. Richter (Eds.), *Topology: Topical thoughts on the contemporary landscape* (pp. 213–226). Berlin: Jovis Verlag.
- Şen, Z. I. (2008). *Wadi hydrology*. Boca Raton: CRC Press.
- Shahin, M. (2007). Wadis and wadi flow. In M. Shahin (Ed.), *Water resources and hydrometeorology of the Arab region* (Vol. 59, pp. 279–332). Dordrecht: Springer.
- Soliman, M. M. (2010). *Engineering hydrology of arid and semi-arid regions*. US: Taylor and Francis.
- Sowers, J. (2011). Climate change, water resources, and the politics of adaptation in the Middle East and North Africa. *Climatic Change*, 104(3–4), 599. Retrieved from <http://unimelb.hosted.exlibrisgroup.com:3410/sfxlcl41?sid=google&aunit=J&aurlast=Sowers&atitle=Climate%20change%2C%20water%20resources%2C%20and%20the%20politics%20of%20adaptation%20in%20the%20Middle%20East%20and%20North%20Africa&id=doi%3A10.1007%2Fs10584-010-9835-4&title=Climatic%20change&volume=104&issue=3&date=2011&spage=599&issn=0165-0009>
- Steward, A. L., von Schiller, D., Tockner, K., Marshall, J. C., & Bunn, S. E. (2012). When the river runs dry: Human and ecological values of dry riverbeds. *Frontiers in Ecology and the Environment*, 10(4), 202–209.
- Tooth, S. (2013). Dryland fluvial environments: Assessing distinctiveness and diversity from a global perspective. In J. F. Shroder (Ed.), *Treatise on geomorphology* (Vol. 9, pp. 612–644). San Diego, CA: Academic Press.
- Tortajada, C. (2014). Water resources: An evolving landscape. In B. Currie-Alder, R. Kanbur, D. M. Malone, & R. Medhora (Eds.), *International development: Ideas, experience, and prospects* (pp. 448–462). United Kingdom: Oxford University Press.
- Walliss, J., & Rahmann, H. (2016). *Landscape architecture and digital technologies: Re-conceptualising design and making*. London: Routledge.
- Wheeler, H., & Al-Weshah, R. A. (2002). *Hydrology of wadi systems: IHP regional network on wadi hydrology in the Arab region*. Paris: Unesco.
- Yin, R. K. (2002). *Case study research: Design and methods*. Los Angeles: SAGE.
- Zeisel, J. (1984). *Inquiry by design: Tools for environment-behaviour research*. Cambridge: Cambridge University Press.

Appendix A

Table A1. Interview questions with designers.

Questions	Themes for the focused interviews with the designers/ engineers
What are the underlying drivers which triggered the project?	The procedure of getting involved in the project
How did you get involve in the project?	The client's agenda and design brief The designers imperatives and visions The budget
How did you tackle levels of uncertainties during the design process?	The hydro-ecological considerations: uncertainties related to sudden floods, re-vegetation, soil erosion, etc. Points of innovations
What data, tools, and methods were used to work with water dynamics and ecological process flows?	The tools and methods for modelling change and working with uncertainties Challenges and limitations
'How did the interdisciplinary collaboration operate?'	The different disciplines involved in the projects
What were the challenges/tensions?	The interdisciplinary collaboration process The ways of communicating ideas Points of compromises
'How did you engage with cultural nuances?'	The fundamental cultural values
'What methods did you use for this engagement?'	Community participation
'What was different from your previous design experiences in terms of cultural consideration?'	Ways of gaining cultural knowledge Manifestation of cultural identity in the design

Table A2. Interview questions with the clients.

Questions	Themes for the focused interviews with the decision makers
What were the drivers for the projects' development?'	Changes in the wadis from past to present
'What was your vision for reviving the wadis?'	Social/ecological and economic aspirations The risks/threats/opportunities and the project development The reason and procedure of commissioning the international designers The current and future visions/re-envisioning the wadis The agenda/brief The budget
Why international designers were involved?'	Ways of facilitating the transfer of local knowledge
'How did they communicate?'	Ways of communicating with the designers Challenges/cultural or language barriers
'What other disciplines were involved?'	The different disciplines involved in the projects
'Were the communities involved in decision making processes?'	The interdisciplinary collaboration process Communities involvement